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ON THE STUDY OF THE SHELF-LIFE OF COMPONENTS OF AUTOMATIC SYSTEMS

\- USSR -

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ON THE STUDY OF THE SHELF-LIFE OF COMPONENTS OF AUTOMATIC SYSTEMS

[Following is a translation of an article by G. V. Druzhinin in Izvestiya Akademii Nauk, otdelenie tekhnicheskikh nauk, Energetika i Avtomatika (News of the Academy of Sciences, Department of Technical Sciences, Power Engineering and Automation), No. 6, 1959, Moscow, pages 141-150]

The peculiarities of studying problems of shelf life of automatic elements are examined in this article. For the study of shelf life and of the reliability of the elements, it is proposed to utilize linear random functions, all realizations of which are straight lines. The properties of these random functions are described briefly. The problem is considered concerning the computation of the basic characteristics of the shelf life of automatic elements -- of the law of distribution of the hold-up time in operable condition.

A number of the most important properties of automatic elements is related shelf-life, that is, the capability to be found in proper condition in the process of storing. In other words, shelf-life is the reliability of non-operating (stored) elements and systems. One can usually consider the operation of elements (found under current or voltage) as a particular case of storage.

For the qualitative measure of shelf-life, let us apply, by analogy with the common qualitative determination of reliability, the probability s of finding the element or the system in an operable condition in the course of the assigned time t of storage under definite conditions. We will call the relationship s(t) the shelf-life function. The shelf-life function s (t) or the theory of probability of hold-up time in proper condition is $f(t) = -\frac{ds(t)}{dt}$ or the breakdown rate $\lambda(t) = \frac{f(t)}{s(t)}$ characterize the shelf life of an element or a system.

Prediction of the shelf-life consists of computation of one of these characteristics.

1. The determining parameter of an element as a random function of time. During storage, the basic bulk of failures occurs owing to aging of the elements. Every element has the determining parameter η which can serve as a measure of its quality. The determining parameter of an element occasionally changes in the process of storage (the element ages).

During aging, a variation of the determining parameter of an element usually occurs monotonously and in one direction for all elements of a given type. For example, all carbon composition resistors monotonously decrease their conductivity with the passage of time.

The determining parameter of an element, during its change, can achieve a critical value during which the condition of the element is considered unsatisfactory, that is, the element goes out of order [breaks down]. This critical value of the determining parameter is established as a constant for a group of similar elements which are in storage and which are not connected to a system. If one considers the devices (systems) which consist of many elements, then the critical value of the parameter η for each element will be determined by the location of the element in the skeleton diagram of the system. For brevity's sake, the critical value of the determining parameter we will sometimes call the limit of the element.

Breakdowns (failures) of elements owing to aging are called progressive which indicates the character of their origination. The moment of appearance of a progressive failure can be forecast. This can be achieved either by means of observation of the behavior of each specific elements (boundary control [1]) or the problem can be examined statistically. The determining parameter of the element can be considered as a random function of time H (t). At a fixed moment of time t_i, the value of the determining parameter will be the random value H_i. In principle, H (t) can be considered as a vectorial random function of time. The below presented results are easily generalized for the case of an n-measured random vector. However, in practice, there does not usually arise the need for such a generalization.

In the process of storage, along with gradual failures, a certain number of sudden failures of elements is observed. During sudden failures, there takes place a sharp, practically instantaneous changes of the elements' characteristics. The discontinuities of $\eta_j(t)$ of the random function H(t) correspond to sudden failures of the elements. The time of occurrence of the railization discontinuity $\eta_j(t)$ is a random value. Owing to this, the random function H(t) is continuous even in the presence of sudden failures. It follows from the determination [2] of the continuity of a random function. The determining parameter of an element can always be chosen so that it would decrease with the passage of time and during a sudden failure $\eta = \emptyset$.

In accordance with the stated [remarks], a sudden failure can be considered an individual occurrence of the change of the elements' parameter and correspondingly can proceed during the computation of the characteristics of the random function H(t) according to the experimental data. Under conditions of storage, it is practically impossible to achieve continuous control of the elements' adjustment.

Information concerning sudden failures is obtained only periodically at the moments of measurement of the elements' parameters. Therefore, during computation of the characteristics of the random function H(t) according to the experimental data, it is necessary to consider as equal to zero the values of the determining parameters of the elements which suddenly fail at a given moment of time in storage.

Thus, in the general case of the presence of both types of failures, one can utilize methods developed under the supposition that all failures of elements are gradual.

The assumption concerning the normal law of distribution $f_i(\gamma_i)$ of the values of the determining parameter of an element at any fixed moment of time t_i are in good agreement with the experimental data. Therefore, further discussion will frequently be conducted under the assumption that the random function H(t) is distributed normally.

Study of the shelf-life of elements by means of the examination of random functions H(t) has the following features:

1. The variation of the determining parameter of each specific element during the course of storage time can usually be approximated as a linear function with sufficient accuracy.

2. Usually an element ages morally [moral'no] more rapidly than physically. Therefore, any study of shelf-life is always associated with the extrapolation of the determining parameter of the element. The forecast of the shelf-life is principally distinguished by this from a forecast of the reliability or the accuracy of elements and systems of transitory effect, where the results of tests of elements statistically characterize their properties. Linear extrapolation is more simple and convenient.

3. The opportunities of conducting measurements of the values of the elements' determining parameters are very limited. In many cases, in the process of storage or exploitation, it is possible to measure only once the values of the determining parameter of similar elements.

2. <u>Concerning the extrapolation of the determining parameter for a minimum number of measurements</u>. The above indicated features of the study of the shelf-life of elements define the necessity of applying linear extrapolation of an element's determining parameter. In addition, it is convenient to consider the determining parameter H(t) as a linear random function of time, that is, as a random function, all realizations of which are straight lines.

A linear random function of time H(t) is the linear function of two random arguments: of the initial ordinate H_0 and of the angular coefficient B of a straight [line]

$$H(t) = H_0 + Bt \tag{2.1}$$

The expected value of a linear random function is

$$m_{\eta}(t) = m_{\eta_0} + m_b t \tag{2.2}$$

where m_{η_0} -- is the expected value of the initial ordinate H_0; m_b -- is the expected value of the angular coefficient B.

The correlation function of a linear random function is

$$K_\eta(t,t') = D_{\eta_0} + (t+t')K_{b\eta_0} + tt'D_b \tag{2.3}$$

Here, D_{η_0}, D_b -- is the variance of the initial ordinate H_0 and of the angular coefficient B, $k_{b\eta_0}$ -- is the coupling moment of these random values.

Assuming in formula (2.3) that $t = t'$, we will obtain the formula for the variance of a linear random function

$$D_\eta(t) = D_{\eta_0} + 2tk_{b\eta_0} + t^2 D_b \tag{2.4}$$

Utilizing formula (2.4) one can represent formula (2.3) as

$$K_\eta(t,t') = D_\eta(t) + \frac{1}{2}\frac{dD_\eta(t)}{dt}(t-t') \tag{2.5}$$

Thus, the variance of a linear random function determines the form of its correlation function. If the linear random function is disturbed normally, then the expected value $m_\eta(t)$ and the variance $D_\eta(t)$ are its comprehensive characteristic.

One can assign constant numerical characteristic to a normal linear function. One can be convinced of this, having examined formulas (2.2) - (2.4) where all coefficients are constant.

The expected value and the variance of a linear random function can be determined in accordance to the statistical data of two of its sections. Actually, in agreement to formulas (2.2) - (2.4), to determine the expected value $m_\eta(t)$ and the variance $D_\eta(t)$ (or the correlation function $K_\eta(t, t')$ of the linear random function H(t), it is necessary to know the five numerical characteristics: the expected values m_{η_0} and m_b, the variances D_{η_0} and D_b and the correlation moment $k_{b\eta_0}$. The numerical characteristics of these cross sections t_i and t_{i+1}: the expected values m_{η_i} and $m_{\eta_{i+1}}$, the variances D_{η_i} and $D_{\eta_{i+1}}$ and the correlation moment of the cross sections $k_{\eta_i\eta_{i+1}}$.

Let us find the relationships of the numerical characteristics of a linear random function to the numerical characteristics of two of its sections t_i and t_{i+1}.

The angular coefficient of the straight line is

$$B = \frac{H_{i+1} - H_i}{t_{i+1} - t_i} \tag{2.6}$$

The initial ordinate is

$$H_0 = \frac{t_{i+1}H_i - t_i H_{i+1}}{t_{i+1} - t_i} \tag{2.7}$$

In accordance with formulas (2.6), and (2.7)

$$m_b = M[B] = \frac{m_{\eta_{i+1}} - m_{\eta_i}}{t_{i+1} - t_i} \quad (2.8)$$

$$m_{\eta_0} = M[H_0] = \frac{t_{i+1} m_{\eta_i} - t_i m_{\eta_{i+1}}}{t_{i+1} - t_i} \quad (2.9)$$

Utilizing formulas (2.6) - (2.9), one can obtain expressions for the remaining characteristics of the linear random function H(t)

$$K_{b\eta_0} = \frac{(t_{i+1} + t_i) K_{\eta_i \eta_{i+1}} - t_{i+1} D_{\eta_i} - t D_{\eta_i \eta_{i+1}}}{(t_{i+1} - t_i)^2} \quad (2.10)$$

$$D_b = \frac{D_{\eta_{i+1}} + D_{\eta_i} - 2K_{\eta_i \eta_{i+1}}}{(t_{i+1} - t_i)^2} \quad (2.11)$$

$$D_{\eta_0} = \frac{t_{i+1} D_{\eta_i} - 2t_i t_{i+1} K_{\eta_i \eta_{i+1}} + t_i^2 D_{\eta_{i+1}}}{(\tau_{i+1} - t_i)^2} \quad (2.12)$$

Thus, to determine the characteristics of a linear random function of time from the test, it is necessary to measure the values which this function takes at only two instants of time. Moreover, since the initial values of the realizations of a random function (consequently also the numerical characteristics m_η and D_η) are known in practice, then usually the problem of determining the characteristics of the linear random function H(t) results in the measurement of the values of the random variable H_1 at one of the instants of time t_1 and in the computation according to these results of the numerical characteristics D_{η_1} and $K_{\eta_0\eta_1}$. Having established in formulas (2.8), (2.10) and (2.11) $t_i = 0$ and $t_i + 1 = t_1$, one can compute according to available data m_b, D_b, and $k_{b\eta_0}$.

Sometimes, depending on the conditions of the problem, measurement of the values of the various realizations η_j (t) of the random function H(t) at various times (Figure 1) is found to be expedient. If the initial value of the specific realization is known, then it is necessary to conduct still another measurement at any sufficiently remote, from zero, moment of time. During such a method of measurement, the values η_0 and b are individually computed for each realization. The obtained data makes it possible to compute the statistical numerical characteristics m_{η_0}, m_b, D_{η_0}, D_b, and $k_{b\eta_0}$ in accordance to known formulas of the theory of probability.

Let us indicate certain properties of the most simple linear random functions: fan [type] and uniform.

A fan [type] linear random function has a common point for all realizations -- the point is called the pole. The position of each realization depends upon its single random variable -- the angular coefficient B.

A fan [type] linear random function may be written as

$$H(t) = \eta_p + B(t - t_p) \tag{2.13}$$

Frequently, the abscissa of the pole t_p is negative (Figure 2). The characteristics of a fan [type] linear random function are

$$m_n(t) = \eta_p + m_b(t - t_p) \tag{2.14}$$

$$K_\eta(t,t') = D_b(t - t_p)(t' - t_p) \tag{2.15}$$

Assuming in formula (2.15) $t = t'$ is the ratio between the RMS deviations

$$\sigma_\eta(t) = \sigma(t - t_p) \tag{2.16}$$

Thus for fan [type] linear random functions, the RMS deviations depend linearly upon time.

Normally a distributed fan [type] linear random function is determined by four numerical characteristics: η_p, t_p, m_b, D_b

A uniform linear random function is characterized by a constant angular coefficient for all realizations (Figure 3). The initial ordinate H_0 of a straight line is the only random quantity

$$H(t) = H_0 + bt \tag{2.17}$$

Therefore, one can also represent a uniform linear random function as the random quantity, the center of dissipation of which shifts in accordance to linear law with the passage of time. The characteristics of a uniform linear random function have the form

$$m_n(t) = m_{n_0} + bt \tag{2.18}$$

$$K(t,t') = D_{h_0} = const \tag{2.19}$$

Thus, the constancy of its dispersion is the distinctive attribute of a uniform linear random function. According to formulas (2.18) - (2.19), the normally distributed uniform linear random function is completely determined by the three numerical characteristics: m_{η_ϕ}, D_{η_ϕ} and b.

A uniform linear random function possesses an important property for practice: if one plots parallels to the coordimate axes of a section through the given point k for the expected value of the function (Figure 3), then:

a) The coordinants of point k will be the expected values of the random quantities which correspond to the sections

$$\eta_K = M[H_K], \qquad t_K = M[t_K] \tag{2.20}$$

b) The dispersions of the random quantities in the sections will be associated with the relationship

$$D_{\eta_K} = b^2 D_{t_K} \tag{2.21}$$

This property follows because in the considered sections, the random quantities H_k and T_k are association with the linear relationship

$$H_K - \eta_K = b(T_K - t_K) \tag{2.22}$$

Inagreement to (2.22), when the law of distribution H_k is normal, the law of distribution T_k will also be normal.

The possibilities of the application of linear random function are not limited by questions of shelf-life (reliability). They can be found useful during the solution of the series of applied problems.

3. <u>Computation of the law of distribution for the hold-up time of elements in proper condition</u>. An element is considered operable if the value of its determining parameter is greater than the critical value ω. At the fixed moment of time t_i, the probability $g_{\omega i}$ is that the element is operable (that is, that the value of its determining parameter H_i is greater than ω) is expressed by the formula

$$G_{\omega i} = \int_{\omega}^{\infty} f_i(\eta)\, d\eta \tag{3.1}$$

where $f_i(\eta)$ -- is the probability density of values of the determining parameter at the "i" section.

If the random function H_i is distributed normally, then

$$G_{\omega i} = \int_{\omega}^{\infty} \frac{1}{\sigma_{\eta_i}\sqrt{2\pi}} \exp\left[-\frac{(\eta - m_{\eta_i})^2}{2\sigma_{\eta_i}^{\,2}}\right] d\eta \tag{3.2}$$

Here $m_{\eta i}$ -- is the mathematical expectation of the values of the determining parameter at the "i" section, and $\sigma_{\eta i}$ -- is the RMS deciation of values of the determining parameter from the mean value.

One can rewrite formula (3.2) as

$$G_{\omega i} = \frac{1}{2} - \Phi(u_i) \tag{3.3}$$

where

$$u_i = \frac{\omega - m_{\eta i}}{\sigma_{\eta i}} \tag{3.4}$$

where $\Phi(u_i)$ -- is the function of Laplac.

The probability that the element will go out of order during the time (t_i, $t_i^* = t_i + \Delta t$) will be equal to a decrease during this time of the probability that the element is operable

$$q_i(\Delta t) = \Delta G_{\omega i} = G_{\omega i} - G_{\omega i^*}$$

Substituting the increment $\Delta G_{\omega i}$ by the differential when $\Delta t \to 0$, we have

$$q_i(dt) = -dG_{\omega i} = dR_{\omega i} \tag{3.5}$$

where $R_{\omega i} = 1 - G_{\omega i}$ -- is the probability that the element is not operable at the moment of time t_i if the critical value of the determining parameter is equal to ω.

On the other hand, the probability [of the element] going out of order during the time (t_i t_i + dt) is equal to

$$q_i(dt) = f_\omega(t)\big|dt_{t=t_i} \tag{3.6}$$

f_ω (t) -- is the density of probability of hold-up timeof the element in operable condition if its limit is equal to ω.

From (3.5) and (3.6), we have

$$f_\omega(t)\Big|_{t=t_i} = -\frac{dG_\omega(t)}{dt}\Big|_{t=t_i} = \frac{dR_\omega(t)}{dt}\Big|_{t=t_i} \tag{3.7}$$

Thus, the density of probability of the hold-up time in operable condition $f_\omega(t)$ (or, in other words, the density of probability for the time of a failure appearing) is the rate of change of the probability $R_{\omega i}$ that the element is not operable.

In accordance with (3.7), the probability of a failure appearing during the time $\Delta t_i = t_i + 1 - t_i$ is equal to a decrease during this same time of the probability that the element is operable (or to an increment of the probability that the element is not operable)

$$R_\omega(\Delta t_i) = G_{\omega i} - G_{\omega(i+1)} = R_{\omega(i+1)} - R_{\omega i} \tag{3.8}$$

In accordance with (3.7) - (3.8), the shelf-life of an element depends upon the nature of the change of the value $G_{\omega i}$ with time, but the value of the probability $G_{\omega i}$ that the element at the moment of time t_i is operable still does not determine its shelf-life (reliability). In other words, one can speak only about the shelf-life (reliability) of an element in that case when the segment of time of its existence $(t_i, t_i + 1)$ is indicated.

When $t = 0$, that is, at the moment of issuance from the factory, the element will also be operable with the certain probability $G_{\omega\phi}$. At the factories, a series of measures are taken for decreasing the initial dispersal of the determining parameter's values. Therefore, the value of probability $G_{\omega\phi}$ is close to one. In accordance to the value $G_{\omega\phi}$, one can judge concerning the homogeneity of the product produced by the factory; however, nothing can be said concerning its reliability. It is necessary to know the characteristics of the random function $H(t)$ in order to judge the reliability of elements of a given type.

When computing the density of probability of the hold-up time of an element in operable condition, it is necessary to solve a quite unusual problem for the theory of random functions: in accordance to the characteristics of the random function $H(t)$, one finds the law of distribution of a random function at one of the horizontal (that is, parallel to the axis t) sections. Since the characteristics of the random function $H(t)$ are computed in accordance to the values of the random quantities H_1, H_2, ... in the vertical sections, then the problem virtually consists of determining the law of distribution of a random quantity in one of the possible horizontal sections according to the values of the numerical characteristics of a minimum number (two) of vertical sections.

Upon actual computation of the density of the probability of hold-up time of elements in operable condition, one can proceed in the following manner. The entire range of time, proceeding from the moment of manufacture of the element, is divided into intervals.

For each interval $\Delta t_i = t_{i+1} - t_i$ is found the average value of the density of probability of the hold-up time in operable conditions $f_{\omega i}$ according to the formula which results from (3.8)

$$f_{\omega i} = \frac{G_{\omega i} - G_{\omega (i+1)}}{t_{i+1} - t_i} = \frac{R_{\omega (i+1)} - R_{\omega i}}{t_{i+1} - t_i} \qquad (3.9)$$

If the random function H(t) is distributed normally, then one can express formula (3.9) in accordance with (3.3) and (3.4) via Laplac's function

$$f_{\omega i} = \frac{\Phi(u_{i+1}) - \Phi(u_i)}{t_{i+1} - t_i} \qquad (3.10.$$

where u_{i+1}, u_i are determined in agreement with (3.4). A histogram is constructed in accordance to the obtained values of $f_{\omega i}$ which form a continuous curve

Thus, to compute the average value $f_{\omega i}$, which corresponds to the interval Δt_i, it is necessary to know the laws of distribution of the element's determining parameter at the beginning and end of this time interval. For the normally distributed random function H(t), it is sufficient to know only its characteristics $m_\eta(t)$ and $\sigma_\eta(t)$ according to which the values m_η and σ_η, which correspond to the beginning and end of each of the intervals Δt_i, are found.

The characteristics of the linear random function H(t) may be determined from a test according to the results of the measured values of the determining parameter of similar elements at the two moments of time t_i and t_{i+1}. Moreover, the relationships $m_\eta(t)$ and $\sigma_\eta(t)$ can be found according to formulas (2.2), (2.4) and (2.8) - (2.12).

Thus, the probability of a hold-up time in operable condition may be determined by utilization of formula (3.7). For the normally distributed random function H(t), we have after conversion

$$f_\omega(t) = \frac{\sigma_\eta(t)\, m_b - \frac{d\sigma_\eta(t)}{dt}\left[m_\eta(t) - \omega\right]}{\sigma_\eta^2(t)\sqrt{2\pi}} \exp\left\{-\frac{\left[m_\eta(t) - \omega\right]^2}{2\sigma_\eta^2(t)}\right\} \qquad (3.11)$$

According to general formula (3.11), one can find the laws of distribution of the hold-up time in operable condition for various individual types of normally distributed random functions. Having substituted in formula (3.11) the values $m_\eta(t)$, $\sigma_\eta(t)$, and ω in accordance to (2.14) and (2.16), and having designated $m_b/\sigma_t = c$, we will obtain after conversion, the formula of the density of probability of the element's hold-up time in operable condition for the normally distributed fan [type] linear random function H(t)

$$f_\omega(t) = \frac{c(t_\omega - t_{err})}{\sqrt{2\pi}\,(t - t)^2} \exp\left[-\frac{c^2(t - t_\omega)^2}{2(t - t_{err})^2}\right] \qquad (3.12)$$

where t_ω -- is the abscissa of the point of intersection of the straight lines $m_\eta(t)$ and $\omega = \text{const}$.

For uniform linear random function, the moment of time t_ω will be the expected value (the average value) of the element's hold-up time in operable condition when the limit of the element is equal to ω.

For a normally distributed linear random function H(t), making a substitution of the variable in formula (3.11) according to (2.18) and (2.21), we will obtain after conversion the normal law of distribution of an element's hold-up time in operable condition

$$f_\omega(t) = \frac{1}{\sqrt{2\pi}\,\sigma_t} \exp\left[-\frac{(t-t_\omega)^2}{2\sigma_t^2}\right] \tag{3.13}$$

where σ_t -- is the RMS deviation of the element's hold-up time in operable condition from the average value for the critical value of the determining parameter which is equal to ω .

Thus, when the normally distributed linear random function H(t) is uniform, computation of the density of probability of the hold-up time in operable condition results in determinig t_ω and σ_t from the very simple equations (2.18) and (3.21). Therefore, one can raise the question concerning [whether] the substitution of the available normally distributed linear random function is equivalent to its uniform linear random function. We will conditionally call such a substitution the equalization of linear random function H(t).

Upon substitution of the linear random function H(t) of the uniform linear random function H*(t), an error arises in the calculation of the density of probability of the hold-up time in operable condition. It is necessary to choose the parameter of the univorm linear random function H*(t) so that this error would be minimal. Overall consideration of the question concerning equalization of a linear random function goes beyond the confines of this article. Let us consider only one individual occurrence.

When special accuracy is not required or when the random function H(t) is close to the uniform [function] H*(t) (that is, the dispersion D (t) changes little), one can assume

$$\begin{aligned} b^* &= m_b \\ m_{\eta_0}^* &= m_{\eta_0} \end{aligned} \tag{3.14}$$

and the RMS deviation σ_η of the element's determining parameter is considered constant and equal to its mean value during the variation of the parameter from η_0 to η_ω

$$\sigma_{\eta_{avg}}^* = \frac{1}{2}(\sigma_{\eta_0} + \sigma_{\eta_\omega}) = const \tag{3.15}$$

Moreover, the numerical characteristics t_ω and σ_t of the normal law of distribution of the hold-up time in operable condition can be approximately determined by two measurements of the parameter η in the storage process. The value t_ω is found from the equation

$$\omega = m_{\eta_0}^* + b^* t_\omega \tag{3.16}$$

Having substituted the values b* and m_{n_ϕ}* according to (2.8) and (2.9) in (3.16), we have

$$t_\omega = \frac{(t_{i+1} - t_i)\omega - t_{i+1} m_{n_i} + t_i m_{n_{i+1}}}{m_{n_{i+1}} - m_{n_i}} \tag{3.17}$$

where m_{n_i}, $m_{n_{i+1}}$ -- are the mean values of the element's determining parameter at the moment of time t_i.

Extrapolating linearly the RMS deviation of the element's determining parameter from its mean value, we have

$$\sigma_{n_\omega} = \frac{\sigma_{n_{i+1}} - \sigma_{n_i}}{t_{i+1} - t_i} t_\omega + \frac{t_{i+1}\sigma_{n_i} - t\,\sigma_{n_{i+1}}}{t_{i+1} - t_i}$$

$$\sigma_{n_0} = \frac{t_{i+1}\sigma_{n_i} - t_i \sigma_{n_{i+1}}}{t_{i+1} - t_i}$$

Substituting the value $\sigma_{n\,\omega}$ and $\sigma_{n\,\phi}$ in formula (3.15) and taking into consideration (2.21), we will obtain

$$\sigma_t = \frac{(\sigma_{n_{i+1}} - \sigma_{n_i}) t_\omega + 2(t_{i+1}\sigma_{n_i} - t_i \sigma_{n_{i+1}})}{2(t_{i+1} - t_i)} \tag{3.18}$$

Having computed the values t_ω and σ_t according to formulas (3.17) and (3.18), one can find the probability of failure (1 - s) of the element during storage time t according to formula [3]

$$1 - s = \frac{1}{2} - \Phi(v) \tag{3.19}$$

where

$$v = \frac{t_\omega - t}{\sigma_t} \tag{3.20}$$

but $\Phi(v)$ -- is Laplac's function.

The shelf-life of the element, in accordance to (3.19), will be

$$s = \frac{1}{2} + \Phi(v) \tag{3.21}$$

Setting several values of t, one can compute and plot the shelf-life function s(t), according to which one can judge concerning the possibility and the expediency of the equipment's future storage.

If in the process of storage, there is the opportunity to repeat measurement of the values of the elements' parameters, then the above stated method can be applied repeatedly. Moreover, by means of successive approximations, one can obtain still more accurate computational results.

Submitted October 1, 1959

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FIGURES

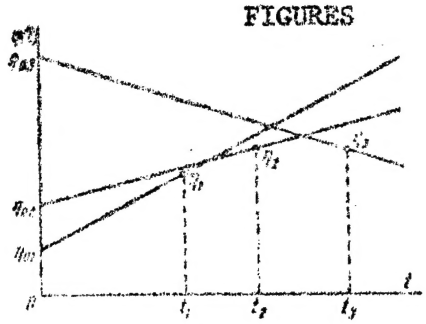

Figure 1. One of the methods for measurement of the realized values of a linear function.

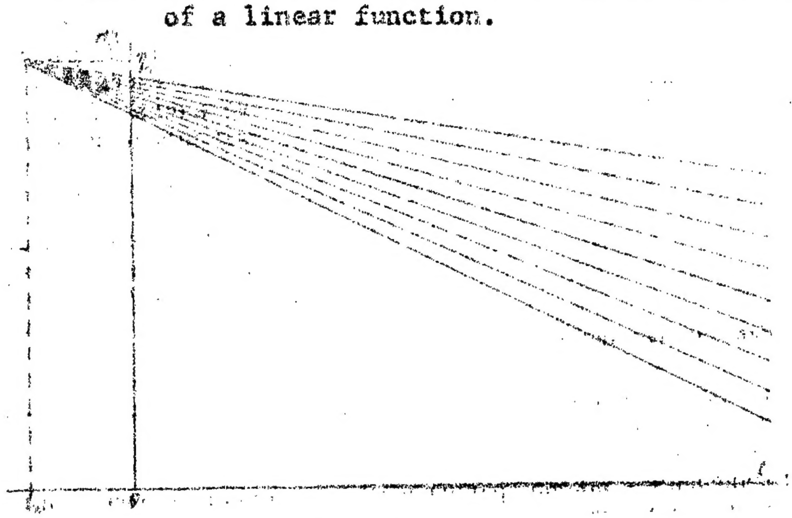

Figure 2. A fan [form] linear random function.

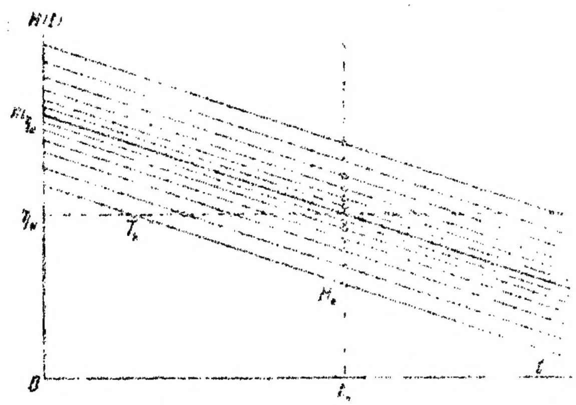

Figure 3. A uniform linear random function.

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